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RESEARCH AND DEVELOPMENT OF AN ADVANCED PERSONAL LOAD CARRIAGE SYSTEM PHASES II AND III

EXECUTIVE SUMMARY

by

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14. ABSTRACT

(U) This contract is a continuation of an earlier DCIEM contract (#W7711-447225/01-XSE) to review current load carriage (LC) designs and knowledge of LC systems and to develop a validated measurement system for LC assessment. The overall objectives of this contract were to develop improved assessment tools and to use these tools in further development of a valid and reliable measurement procedure for military LC assessment. The specific objectives are defined in each of Sections (A-E) which are bound as separate.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U)

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Research and Development of an Advanced Personal Load Carriage System Phases II and III

EXECUTIVE SUMMARY

1.0 Introduction

The Defence and Civil Institute of Environmental Medicine (DCIEM) has contracted Queen's University to assist in the research and development of an Advanced Personal Load Carriage System (APLCS) in support of the Canadian Forces Soldier Modernization Program, as part of a major crown project D6378 Integrative Protective Clothing and Equipment (IPCE). It is recognized that soldier survival, sustainability, and performance in the field will often require carrying significant loads consisting of operation specific equipment, armaments, protective equipment, and provisions, in future conflict or peacekeeping operations. It is also recognized that soldier survival may depend on carrying moderate to heavy loads over short or long distances. Therefore, the next generation of PLCS should be designed to be compatible with the range of soldier physical, physiological and biomechanical capabilities to optimize soldier performance and operational effectiveness. In addition to this next generation project, another major crown project L2646, Clothe The Soldier (CTS), also has immediate needs for improved PLCS. Both the CTS project, and eventually the IPCE project, require a cost effective and reliable method by which various load carriage equipment designs and components can be tested, evaluated and approved for further military evaluations with representative users in the field.

2.0 Objectives

This contract is a continuation of an earlier DCIEM contract (#W7711-47225/01-XSE) to review current load carriage (LC) designs and knowledge of LC systems and to develop a validated measurement system for LC assessment. The overall objectives of this contract were to develop improved assessment tools and to use these tools in further development of a valid and reliable measurement procedure for military LC assessment. The specific objectives are defined below. Each of Sections (A-E) are bound as separate reports.

2.1 Section A: Further Development of Comprehensive LC Measurement System

Section A of the report is a synopsis of the research work involved in enhancing the LC assessment tools. This comprised making improvements to the Load Carriage Simulator and the Torsional Stiffness Tester which were developed under contract #W7711-47225/01-XSE.

The specific objectives to improve the Load Carriage Simulator (LC Sim) were:

A.1 Add a load cell for measurement of ground reaction forces; this would be used for load carriage vest and fragmentation vest trials (Scope 7a1).

A.2 Extend the LC Sim motions beyond level walking and branch duck to include jogging and side slip (Scope 7a2).

A.3 Develop the ability to use interchangeable body sizes representing 5th and 50th percentile females and 50th and 95th percentile males. (Scope 7a4). To accomplish objectives A.2 and A.3, it was necessary to completely revise the control software to the LC Sim and upgrade the control valves to accommodate the range of mannikin weights while maintaining repeatable patterns of motion (added item to Scope 7a4).

A.4 Develop the capacity to measure the pressure distribution across the LC Sim torso surface for use with all operational configurations (i.e., fighting, battle and marching orders) and for different equipment and clothing items. (Scope 7a5).

A.5 Create and document user-friendly software for load carriage system (LCS) data acquisition and analysis. (Scope 7a7).

The following objective was set to improve the Torsional Stiffness Tester (the redesigned equipment is now called the LC Compliance Tester):

A.6 Improve the torsional stiffness tester to include assessments of lateral bending and flexion extension. (Scope 7b1).

In addition to improvements to existing equipment, the contract scope included the development of three additional items as part of a demonstration project:

A.7 Develop a pack-parts tester (PP Tester) to assess various component items such as shoulder straps, waist belt, load lifter straps and for use in the development of a biomechanical model. (Scope 7e).

A.8 Develop a prototype software program which can be used in conjunction with other design tools to determine and evaluate optimal kit placement based on frequency, criticality and functional relationships. (Scope 7d).

A.9 Develop a demonstration of a portable system for in-field measurements of biomechanical and physiological variables applicable to human LCS testing. (Scope 7c).

2.2 Section B: Evaluation of Pack-Based Systems using the Comprehensive LC Measurement System

Section B of this report describes work done on testing pack-based systems on the LC Sim in normal walking. The torsional stiffness of the pack suspension was measured on the Resistance to Motion tester. The matrix of the tests was agreed upon in the Interim Report to Major L. Bossi (dated March 28, 1996) and is reported below:

B.1 Compare and rank seven (7) pack-based systems in marching order on the LC Sim on the 50th percentile male - mannikin. Ten (10) configurations were tested in marching order, consisting of four (4) configurations of the Canadian '82 pattern, four (4) configurations of the DACME prototype rucksack and one (1) each of the British and Australian patterns. (Scope 7f).

B.2 Determine the effect of wearing either webbing or load carriage vest (LCV) during marching order on the LC Sim on the 50th percentile male mannikin (Scope 7f).

B.3 Determine the effect of wearing a fragmentation vest during marching order under webbing or LCV (Scope 7a6).

B.4 Compare and rank the top three (3) systems in marching order across the different mannikin sizes. Because of logistics in testing and in agreement with the Interim Report (March 28, 1996), only two (2) systems were investigated across different anthropometric mannikins. (Scope 7a4, 7f-2).

B.5 Compare and rank seven (7) pack-based systems in terms of pack stiffness about the three principle axes of trunk rotation. All systems were tested for torsional stiffness; four (4) systems were tested about all three axes of rotation. (Scope 7g).

LC measurement system assessments were conducted on a number of in-service military load carriage systems, namely:

Australian system (A),
British system (B),
Canadian (1982 Pattern) system (C),
DSSPM system (D),
Canadian (1964 Pattern) system (E).

In LC measurement system testing, systems A and B were evaluated with no protective fragmentation vest (FV), since neither system had been designed to be worn over the available FV. Systems C and D were tested with current issue webbing both with and without FV. As well, systems C and D were tested with a modified Bosnian LCV, both with and without FV. Due to a fracture of the frame base, system E was unavailable for LC measurement system testing. Table 2 2-1 summarizes the test configurations for the LC measurement system tests (LC Sim, LC Compliance Test).

Table 2.2-1. Reference codes used to describe the Marching Order test configurations for the LC Measurement System Tests presented in Section B.

BASE SYSTEMS for LC Sim Tests	MARCHING ORDER			
	Pack and Webbing		Pack and LCV	
	No Frag	+Frag	No Frag	+ Frag
A	ANF[1, 2]	-	-	-
B	BNF[1, 2]	-	-	-
C	CWNF[1]	CWF[1, 2]	CVNF	CVF[1, 2]
D	DWNF[1]	DWF[1]	DVNF[1]	DVF[1]

[1] Systems tested for torsional stiffness.
[2] Systems tested for flexion and lateral bending stiffness

2.3 Section C: Evaluation of Pack-Based Systems using the FAST Trials

In an earlier report, Stevenson et al. (1995), described a study of military field trials which was done to extract those movements which were common to many elements of marching or battle order. The standardized military circuit was designed to incorporate the following conditions: marching over different terrains, load control and balance, control of side-slipping and overcoming obstacles. In developing a test battery for military field trials of LC systems, these conditions have been reduced to two main components: load control and load transfer. In addition, a series of high agility tasks were added to mimic a soldier's mobility requirements during battle conditions. The complete test battery was called a First Assessment and Standardized Testing (FAST) trial. These FAST trials were used to collect data with the following objectives:

C.1 Compare and rank seven (7) pack-based systems using FAST trials during marching order. This comparison should be made across objective, and subjective measures (Scope 7h).

C.2 Compare and rank seven (7) pack-based systems using FAST trials during battle order. This comparison should be made across objective and subjective measures (Scope 7h).

C.3 Examine the cost (based on subjective, physiological and performance measures), across seven (7) pack-based systems, of wearing a fragmentation vest as part of the standing order in load carriage situations (Scope 7i).

In the FAST trials, all five base systems were evaluated both with and without FV, for completeness. Two systems (C and D) were evaluated with a modified Bosnian LCV (the modified Bosnian LCV was not designed to be worn under current issue packs A, B or E). Table 2.3-1 outlines the identification codes used for systems in FAST Trials marching order testing, while Table 2.3-2 provides a test code matrix for battle order FAST Trials testing.

Table 2.3-1. Reference codes used to describe the Marching Order test configurations for the FAST trials presented in Section C.

BASE SYSTEMS for FAST Trials	MARCHING ORDER			
	Pack and Webbing		Pack and LCV	
	No Frag	+Frag	No Frag	+ Frag
A	ANF	AF	-	-
B	BNF	BF	-	-
C	CWNF	CWF	CVNF	CVF
D	DWNF	DWF	DVNF	DVF
E	ENF	EF	-	-

Table 2.3-2. Reference codes used to describe the Battle Order test configurations for the FAST trials presented in Section C.

BASE SYSTEMS for FAST Trials	BATTLE ORDER	
	No Frag	Frag
A	AW	AF
B	BW	BF
C	CW	CF
LCV	CV	CVF

2.4 Section D: Comparison of the Comprehensive LC Measurement System and FAST Trial Evaluations

One of the principal aims of this research is to validate the objective measures from the LC Sim and LC Compliance tester by comparison with the human FAST trials. This information can then be used to increase our understanding of load carriage and to rank order LC systems based on a combination of results from subjective and measurement system tests. (Scope 7j).

2.5 Section E: Parametric Analysis of Advanced Personal Load Carriage Systems

Parametric design analysis in this phase of the project involved an evaluation of the effects of differing load placement on the centre of gravity and accessibility of kit, and the development of a computer model for optimizing load configuration, based on centre of gravity. Issues of wearer convenience and comfort, as well as pack capacity and relationship to standard military load, were of significant interest to the APLCS group. (Scope 7d)

2.6 Section F: The TTCP-8-TTC International Military Workshop on Load Carriage

A workshop, organized in collaboration with DCIEM and NDHQ, was hosted for military and civilian personnel from around the world. This workshop was held at Queen's University from October 7 - 10, 1996. The workshop provided a forum for exchange of information among researchers from many countries and for a demonstration of the current state-of-the-art in standardized LC testing equipment. (Scope 7k).

3.0 Overall Results of LC System Testing

3.1 Section A: Further Development of Comprehensive LC Measurement System

1. Numerous improvements to LC Sim measurement systems have improved the breadth and quality of data available from LC system testing. A pictorial representation of the data currently available from LC Sim testing can be found in Figure 3.1-1. This comprises thirty-nine performance measures of contact pressure, relative pack/torso motion, and reaction moments. The testing method is the most comprehensive quantitative measurement system currently available for load carriage assessment worldwide.

   Further development of the pneumatic control system, a novel approach with numerous benefits including flexibility and cost, has also allowed for improved test repeatability. Software improvements performed in-house have enhanced both the testing procedure and data collection. Currently, it is possible to test most torso motions except torsion dynamically and to test rotation statically about three axes.

2. Test protocol standardization has allowed for the development of a benchmark pool of LC system test data, which can be used for evaluation of novel LC systems. These data were collected from both the LC Simulator (Figure 3.1-2) and the LC System Compliance Tester (Figure 3.1-3) and can be compared statistically to any system under evaluation.

3. A prototype portable system which directly measures biomechanical and physiological variables applicable to human LCS testing was developed for use in field trials. Use of the system was demonstrated in one preliminary test and has indicated feasibility for future large scale applications.

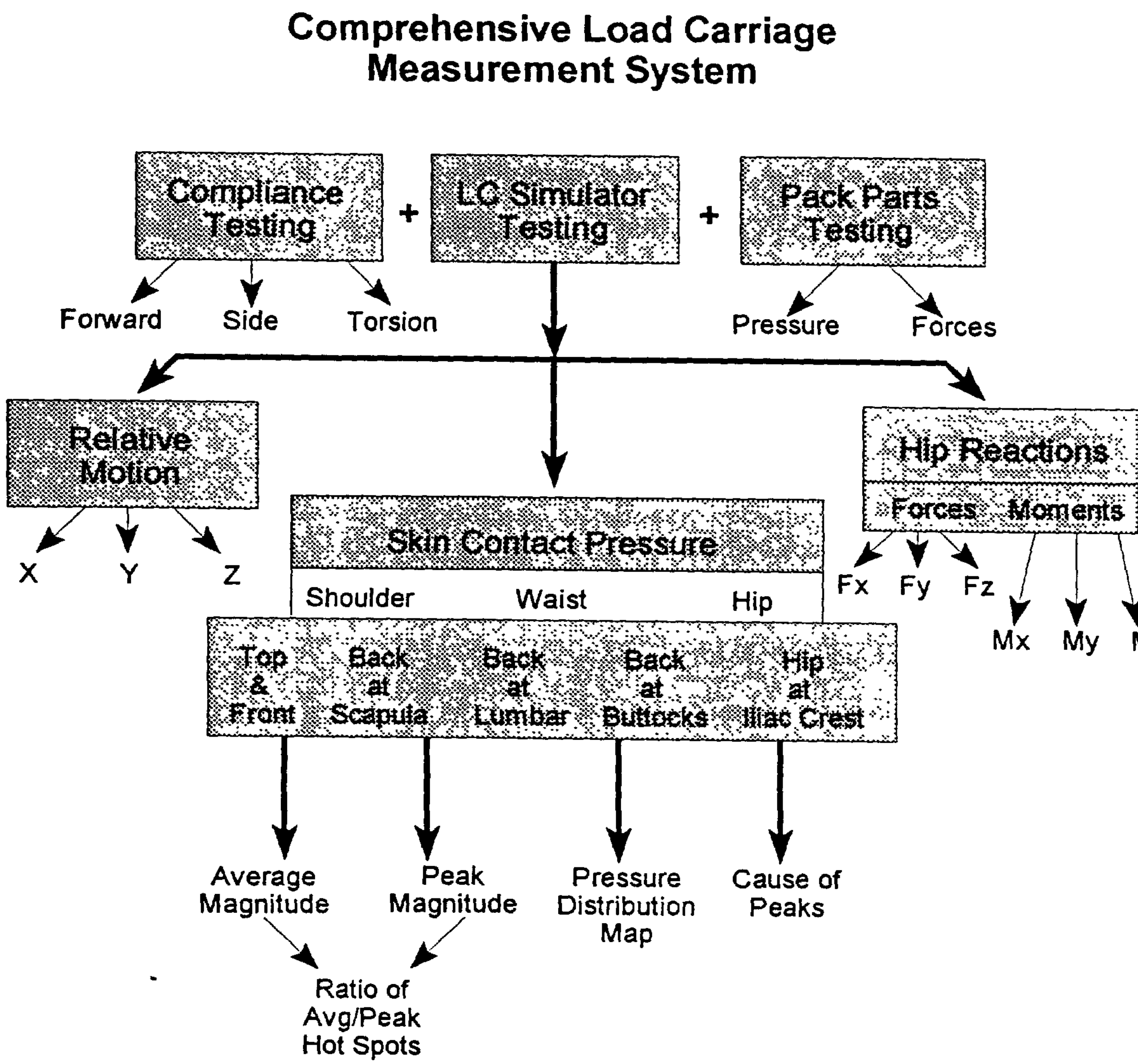

Figure 3.1-1. Flow diagram of data collected in comprehensive LC measurement system testing.

Figure 3.1-2. LC Simulator, with 50 %ile mannikin.

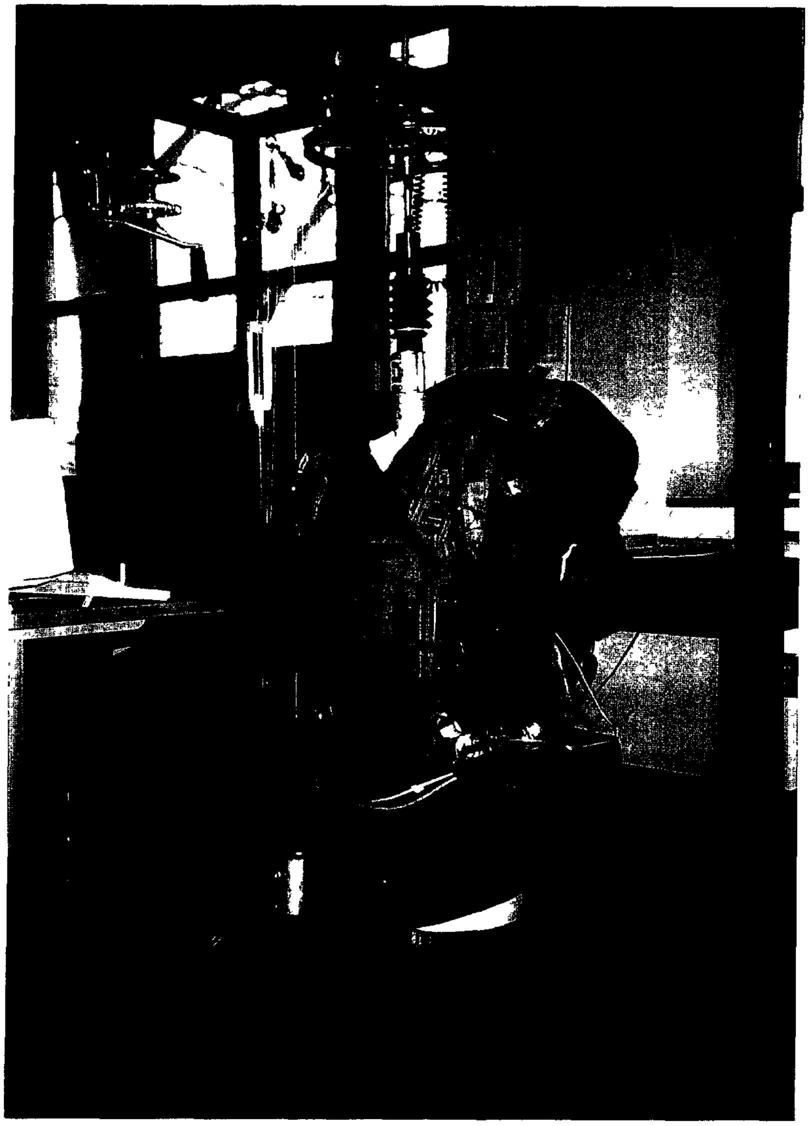

Figure 3.1-3. LC Compliance measurement system

3.2 Section B: Evaluation of Pack-Based Systems Using the Comprehensive LC Measurement System

The following results were generated during LC Sim and LC Compliance testing of the LCS test matrix described in Section 2.2. For ease of comparison, these results are also presented in Table 3.2-1.

1. Of the four (4) base systems tested on the LC Sim, system C gave the largest relative displacements (in x, y and z directions) between the pack and the wearer. The other systems tested gave comparable results, however, systems with external frames (A, C and D) exhibited larger forward/backward displacements than system B which has an internal frame. Large displacements are associated with a loss of load control ability in the LCS

2. The measured values of the reaction moments and forces and amplitudes of reaction moments and forces are indicators of the muscular effort required to overcome these moments and maintain balance. System C was found to have the highest hip moment, which is associated with a high muscular effort at the hip to counter-balance the load. The measured reaction forces were comparable for all systems. However, the upward/downward reaction force at the hip was greatest for system B. System B is a short, shoulder-carried system which requires less forward lean to balance than the other systems; hence a greater downward force component is present at the hip. While this is good in terms of force distribution over the larger area of the hip belt, downward forces of excessively large value could cause compressive damage of the spine.

3. All systems exceeded the recommended maximum average contact pressure (20 kPa) at the shoulders. This value is associated with occlusion of blood flow in the skin over long periods of time. No system exceeded the recommended maximum peak pressure (120 kPa) which is associated with skin tissue damage after short duration. System B exhibited the highest shoulder pressures with a pressure peak on top of the shoulder. Systems B and D exceed the recommended maximum average pressures on the upper lumbar spine . System C, which gave acceptable pressure and body force results on the lumbar spine, exhibited very high body force in the lower lumbar / sacral region. When load carriage systems are worn for long durations, regions of high pressure or high body forces are prone to discomfort, muscular fatigue and pressure point induced tissue injuries.

4. The performance of system C was improved by the addition of the FV. Pack-person relative motion was reduced and reaction forces and moments, and force and moment amplitudes were decreased in all directions, suggesting that the muscular effort required of a wearer to maintain balance would be reduced. However, addition of the FV caused pressure increases in the shoulder, lower lumbar, and sacral regions. Results for system D changed only modestly with the addition of the FV, indicating that there was good integration between system D and FV.

5. Systems B and C were tested on the LC Sim using mannikins of three different sizes - one representing each of a 5^{th} percentile female, 50^{th} percentile male and 95^{th} percentile male. Results indicated that both system designs disproportionately penalized smaller body types.

Table 3.2-1. Comparative summary of major findings.

Variables	System A	System B	System C	System D
Relative Displacement			Suspension allows 18.8 mm total motion in x and y directions.	
Reaction Moments			Total = 56.4 Nm, thus muscular effort needed in all directions.	
Reaction Forces	Need muscular effort to counter forward forces.			
Amplitude of Reaction Moments			Suspension allows twice as much motion as other systems.	
Amplitude of Reaction Forces		Higher CofG produces greater x and z forces.		
Pressure on Top/Front Shoulder		Highest average and peak pressures, body forces 3-4 times higher.		High peak pressure point, 2-3 times higher body forces.
Pressure on Upper Back and Shoulder	Peak pressure point due to shoulder strap design.			
Total Shoulder Load	Exceeds design guidelines.	Exceeds design guidelines and more prone to muscular fatigue.	Exceeds design guidelines.	Exceeds design guidelines and more prone to muscular fatigue.
Pressure on Lumbar Area		Average pressure 3 times other systems.		Average pressures 4 times other systems.
Pressure on Sacrum			Average pressure 2 times and body forces 6 times other systems.	
Total Back Load	Exceeds design guidelines.	Exceeds design guidelines.	Exceeds design guidelines.	Exceeds design guidelines.

3.3 Section C: Evaluation of Pack-Based Systems using the FAST Trials

Results presented in this section were generated during human factors testing of LCS, as outlined in Section 2.3. Again, the results are also presented in table format for ease of comparison between systems. Table 3.3-1 is a synopsis of results for marching order testing while Table 3.3-2 provides a comparison of battle order testing results.

1. Of the five (5) base systems tested (in the NF configuration), system B was clearly rated as superior by users, followed by system E. These systems, which by design or practice favour shoulder loads, are preferred. Systems with significant horizontal or shear load transfer to the lower body, which resulted in more discomfort in the lower back (System A and D) rated lower. System C rated inferior in all final summary categories.

2. System integration between the ruck, LCV/webbing, and FV is important for user acceptability:
    - System B was the most sensitive to a loss in performance when worn with FV. However, in the overall ratings, B still ranked as superior.
    - The acceptability of systems C and D improved when worn with FV However, these systems still ranked as inferior in the overall ratings.
    - System C ratings improved to acceptable (but not superior) values with the LCV compared to the webbing.
    - System D ratings decreased with the LCV, compared to the webbing.

3. Battle order systems with a smaller profile - BW and LCV - received the highest ratings for battle order testing.

Table 3.3-1. Comparative summary of major findings from marching order testing.

Variable	System A	System B	System C	System D	System E
Balance			Lowest score, in inferior range.		
Load Control		Superior score.	Inferior score.		
Agility		Superior score.	Inferior score.		
Static Tasks	Superior in trunk flexion and rotation.	Inferior in emergency doff, superior in bending and rotation.	Inferior in hands above head and lateral bending.	Inferior in hands above head and lateral bending.	
Summary		Superior in acceptability, mobility, and thermal comfort.	Inferior in all areas.	Inferior in all areas.	Inferior in physical comfort.
Discomfort Scores			High discomfort in front and rear shoulders.	High discomfort in front and rear shoulders.	High discomfort in front shoulders.
Integration w/ Fragmentation Vest		Largest decrease in scores with addition of frag vest		Improved scores with fragmentation vest, notably integration and mobility	Less discomfort reported with fragmentation vest.
Overall Ratings	Rank 3.5 / 5.	Preferred in all categories. Rank 1 / 5.	Least preferred in all categories. Rank 5 / 5.	Rank 3.5 / 5	Superior scores for balance and fit. Rank 2 / 5

Table 3.3-2. Comparative summary of major findings from battle order testing.

Variable	AW	BW	CW	LCV
Horizontal Mousehole	Inferior score for entry.		Inferior on entry and exit.	
Vertical Mousehole		Superior scores for climbing and exit.	Inferior scores for climbing and exit.	
Leopard Crawl		Superior score for agility.	Inferior on comfort and agility.	Superior on comfort and agility.
Over / Under		Superior score for crawling under obstacle.		
Arm Tasks	Superior scores.	Superior scores.	Superior scores.	Superior scores.
Trunk Tasks	Superior for flexion, lateral bending, and rotation.	Superior for flexion, lateral bending, and rotation.	Superior for rotation.	Superior for flexion, lateral bending, and rotation
Total Body Tasks		Superior for all activities.		Superior on all activities except canteen access.
Summary		Superior scores in all areas.	Inferior score for durability.	Superior scores on acceptability and mobility.
Discomfort Scores		Lowest shoulder discomfort.		Lowest discomfort in all areas except shoulders.

3.4 Section D: Comparison of Results from Comprehensive LC Measurement System and FAST Trial Evaluations

LC Measurement System measures were shown to be significantly correlated with FAST Trials results, as presented in Tables 3.4-1 and 3.4-2, for displacement, moment, force, pressure, and stiffness variables. The following conclusions arose from this work :

1. Standardized physical testing is an effective method of load carriage evaluation for military use, based on strong correlation of human trials results with simulator measures in twenty-one of the thirty-nine measured variables.

2. A dynamic pool of load carriage testing measures has been created. This allows the direct comparison of a system under evaluation to the performance of all load carriage systems within the test pool.

3. Based on results of this study and previous studies, number of threshold limit values have been established for load carriage system body forces and contact pressures. In this study, an average shoulder contact pressure of 20 kPa was established as an upper threshold limit, such that discomfort scores are maintained at an acceptable level for users.

Table 3.4-1. Significantly correlated displacement, force, and moment variables.

Correlated LC Simulator and Human Factors Measures
Displacements and Forces

LC Simulator Measures		*Correlated Human Factors Measurements*
Displacement (mm)	x	• Posterior Hip Discomfort
	y	
	z	• Posterior Hip Discomfort
	r	• Postenor Hip Discomfort
Moment (Avg, Nm/kg)	x	
	y	• Forward Flexion Mobility, Overall Comfort, Overall Fit
	z	
	r	
Force (Avg, N/kg)	x	
	y	• Front Mobility, Overhead Mobility, Postenor Shoulder Discomfort, March Thermal Comfort,
	z	• Front Mobility, Overhead Mobility, March Thermal Comfort
	r	
Moment (Amp, Nm/kg)	x	• Torsional Mobility, Overall Mobility, Lie Function, Balance, Agility, Anterior Shoulder Discomfort, March Acceptability, March Comfort
	y	
	z	• Front Mobility
	r	• Posterior Neck Discomfort
Force (Amp, N/kg)	x	
	y	
	z	• Lie Function, Load Control, March Acceptability, March Integration, Overall Balance Overall Comfort, Overall Fit, Overall Maneuverability
	r	• Load Control, March Integration

Table 3.4-2. Significantly correlated pressure and stiffness variables

Correlated LC Simulator and Human Factors Measures
Pressures and Stiffness

LC Simulator Measures		*Correlated Human Factors Measurements*
Shoulder Pressure (ANT)	Av (kPa)	• Posterior Hip Discomfort
	Pk (kPa)	• Doffing Function
	PDI	• Doffing Function
	F (N)	• Posterior Neck Discomfort
Shoulder Pressure (POST)	Av (kPa)	
	Pk (kPa)	• Doffing Function
	PDI	
	F (N)	
Lumbar Pressure (UPPER)	Av (kPa)	
	Pk (kPa)	
	PDI	
	F (N)	• Posterior Discomfort
Lumbar Pressure (LOWER)	Av (kPa)	
	Pk (kPa)	
	PDI	• Front Mobility, Posterior Discomfort
	F (N)	
Stiffness (Nm/deg)	Torsion	• Overhead Mobility, Front Mobility
	Flexion	• Combined Function, Posterior Neck Discomfort, Low Back Discomfort
	Side	• Front Mobility, Anterior Shoulder Discomfort, Anterior Hip Discomfort

3.5 Section E: Parametric Analysis of Advanced Personal Load Carriage Systems

The optimization model developed in this section allows for simulation of different pack designs, kit locations, and can prioritize location of kit in terms of threat, equipment size, and frequency of use. Further work in this area will allow for incorporation of the APLCS biomechanical model of load carriage, for sensitivity analysis of the human body to different equipment configurations and loadings. Improved software will also allow for easier visualization of different packing arrangements and equipment designs.

3.6 Section F: Future Military Workshops on Load Carriage

The LC Workshop held at Queen's University was an excellent exchange of scientific and operational information, with a strong focus on improvements to LCS design. Because of rapid advances in commercial and military LC products, it is recommended that a second workshop be held in conjunction with a new technology demonstration. The Ergonomics Research Group at Queen's University would be pleased to act as host for this workshop.

4.0 Conclusions

4.1 Test Improvements :

4.1.1 Improvements to LC Sim measurement systems and control systems have enhanced the repeatability and quality of data available from the LC system testing. Software improvements have also streamlined the testing procedure, and a more advanced compliance testing system has been implemented. This state-of-the-art test facility can now provide scientific feedback, as well as comparison to a normative data pool, for one load carriage system within two weeks. This standardized test output and short turnaround is valuable for LCS designers. **(Section A)**

4.1.2 Future developments in load carriage testing should include further advancement of the portable LC measurement system, and improvement of the calibration protocol, and subsequent accuracy, of the current pressure measurement system. **(Section A)**

4.1.3 An improved set of human LC trials were developed, which included marching order and battle order activity stations with corresponding subject questionnaires, as well as quantitative measurements of skin surface temperature, core temperature, and heart rate. These FAST Trials isolate subjective responses to load control and load transfer, and provide an effective standardized method of obtaining questionnaire responses. **(Section C)**

4.1.4 A benchmark data pool has been developed, based on LC Sim measurements which significantly correlate with human factors measurements. This pool can be used as a reference for future testing of load carriage systems, and can also be made more rigorous by replacing poorly performing systems with newly tested superior systems. **(Section D)**

4.1.5 A weighted scale of load carriage characteristics, based on significantly correlated LC Sim and FAST Trials variables, will be created such that future pack testing can provide a composite characteristic score. **(Section D)**

4.2 Test Results :

4.2.1 All load carriage systems tested excessively loaded the shoulders under typical load carriage conditions. This result was evidenced in excessive contact pressures, most notable in System B, during LC Sim testing, and was reflected in high reported discomfort scores during human factors trials. (Sections B, C)

4.2.2 Load carriage systems which apply excessive force to the low back region (Systems A, C) received inferior comfort scores for this region in human testing. These scores were more directly related to overall subjective pack perception than shoulder discomfort (Sections B, C)

4.2.3 Proper integration between marching and battle order is essential. While battle order with a slim geometric profile was preferred for battle order tasks, it was not always most suitable for marching order tasks, or for integration. (Section C)

4.2.4 The integration of a fragmentation vest was found to dampen the relative motion and reduce moments generated by the LC system. This result was most noticeable in the human testing for external frame systems. However, significantly increased surface temperatures and thermal discomfort scores were also recorded in human factors fragmentation vest testing. (Sections B, C)

4.3 Recommendations for Further Work :

4.3.1 It is suggested that the comprehensive LC measurement system protocol, which involves both the LC Simulator and the LC System Compliance Tester, be frozen to allow for increased power in comparisons with the data pool.

4.3.2 Improved calibration methods for the pressure measurement system should be sought. Research into better calibration methods, both through literature and in-house, should be conducted to address the unique needs of accurately measuring LCS contact pressures. Feasibility studies of performance of alternative pressure measurement systems in this experimental application should also be conducted

4.3.3 It is also a suggestion of this report that development should be continued with the portable LC measurement system to improve the test longevity. This development should include field work.

Acknowledgments

This report is a deliverable for Public Works and Government Services of Canada contact # W7711-7-7384/001/SRV which is entitled "Research and Development of Advanced Personal Load Carriage Systems II and III".

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This phase of the project has been especially demanding because of our tendency to set idealistic goals for new measurement systems, load carriage designs, modelling for future systems, and desires to 'get it right'. We have an excellent working relationship between the Clinical Mechanics Group and the Ergonomics Research Group that makes these types of projects a lot of learning and fun. Thanks, Tim Bryant, for your ability to see through the forest and find ways to reach our goals. As APLCS project manager at Queen's University, Susan Reid has built, re-built, and invented ways to make the LC Sim and compliance tester the best they can be. It is reassuring to know that we can count on you to come through Sue, with your usual sense of humour. On the human side, there is none better than APLCS assistant manager Jon Doan who has the skills, dedication, and ability to stay 'cool' and 'stick handle' through tough spots. Key players on the PI side have included Ron Pelot from Technical University of Nova Scotia who still amazes me with his patience, and understanding of this project from afar. I value your contribution. Also many thanks to Evelyn Morin, of Electrical Engineering and Computing Science, who is leading the portable system team, and Janice Deakin, whose knowledge of experimental design has been key to asking the right questions. The infrastructure teams from the Clinical Mechanics Group, namely David Siu, Gerry Saunders, and Lee Watkins, have been supportive and instrumental in completion of the tasks. Members of the School of Physical and Health Education who have helped us reach our goals are David Andrews, Bill Pearce, and Pat Costigan. And to the many research assistants who are identified on the section covers, thanks for the part you played in the serious and fun times. This has truly been a great team effort.

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14. ABSTRACT

(U) This contract is a continuation of an earlier DCIEM contract (#W7711-447225/01-XSE) to review current load carriage (LC) designs and knowledge of LC systems and to develop a validated measurement system for LC assessment. The overall objectives of this contract were to develop improved assessment tools and to use these tools in further development of a valid and reliable measurement procedure for military LC assessment. The specific objectives are defined in each of Sections (A-E) which are bound as separate.

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